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SELECTION AND SCALING OF GROUND MOTION RECORDS FOR SEISMIC ANALYSIS USING AN OPTIMIZATION ALGORITHM

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Abstract. *The nonlinear time history analysis and seismic performance based methods require a set of scaled ground motions. The conventional procedure of ground motion selection is based on matching the motion properties, e.g. magnitude, amplitude, fault distance, and fault mechanism. The seismic target spectrum is only used in the scaling process following the random selection process. Therefore, the aim of the paper is to present a procedure to select a sets of ground motions from a built database of ground motions. The selection procedure is based on running an optimization problem using Dijkstra's algorithm to match the selected set of ground motions to a target response spectrum. The selection and scaling procedure of optimized sets of ground motions is presented by examining the analyses of nonlinear single degree of freedom systems.*

1 INTRODUCTION

In the last two decades, seismic analysis and design procedures shifted from the conventional force based methods to displacement based methods. The main advantage of the displacement based methods is the detailed information provided for the structural systems in terms of deformation and damage levels. Such high level of information helps the stakeholder to assess and evaluate the buildings' stock when hit by a specified seismic hazard. Performance based method is one of the popular approaches used for seismic displacement based design and assessment. The method is iterative in its nature and needs extensive analysis methods in order to verify the structural performance levels. An example of such methods of analysis is the nonlinear dynamic analysis, which requires an appropriate set of ground motion records. The selection and scaling of these ground motion records is very important as it affects significantly the analysis results and consequently the design recommendations [1, 2, 3]. In the last decade, there has been work concerned with the selection and scaling of existing ground motions. Naeim et al. [4] used a genetic algorithm to create the appropriate set of time histories for nonlinear analysis based on a target design response spectrum, whereas, [5] used a greedy algorithm to determine the set of ground motions using a probabilistic definition of a target response spectrum in terms of mean and variance. This study is concerned with the selection and scaling of ground motions considering two part optimization objective, and furthermore, test the optimized sets using a nonlinear analysis of Single Degree of Freedom System (SDOF) and draw recommendations for the selection process.

2 SELECTION & SCALING OF GROUND MOTIONS USING AN OPTIMIZATION ALGORITHM

2.1 Ground motion database

Ground motions are collected from the Next Generation Attenuation (NGA) database [6]. For each ground motion, the two horizontal components are retrieved and stored, and for each of these components a response spectrum is derived. In total, a 3551 ground motion records are stored in the database and these are used in the optimization problem. Furthermore, subsets of ground motions based on the earthquake's magnitude, fault mechanism and epicenter distance can be obtained from the database, and these subsets can be used in the optimization problem.

2.2 Selection & Scaling algorithm

The objective of the selection of ground motions is to identify the best combination of ground motions and the corresponding scaling factors for the ground motions to minimize the difference between the given design spectrum and the average of scaled ground motions. Furthermore, in the selection process the condition of having the records spectrum between T_o and T_n higher than the target spectrum is accounted for. The first part of the optimization objective (Case 1) is formulated as the minimization of the error term (R)defined by the following relation,

$$R = \sum_{T_o}^{T_n} \left(\frac{\sum_{i=1}^{m} (S_i.Sa_i)}{m} - F_t(T) \right)^2 \tag{1}$$

in which, T is the vibration period, S_i is the scaling factor for the time record i, Sa_i(T) is value of spectral acceleration of record i at period T, F_t(T) is the value of the target design spectrum at period T, T_o is the initial period to consider, T_n is final period to consider, and m is number of records considered. Moreover, the following must be satisfied

$$S_{min} \leq S_i \leq S_{max} \tag{2}$$

where, S_{min} is the minimum acceptable scaling factor, and S_{max} is the maximum acceptable scaling factor. The second part of the optimization objective (Case 2) adds a penalty on the time records which its spectrum values lie below the target design spectrum, satisfying the following relation for all periods $T_o < T < T_n$

$$((S_i.Sa_i) - F_t(T)) < 0 \tag{3}$$

This penalty add an additional error term to the error in equation 1.

The optimization problem is solved using Dijkstra's algorithm, which is also known as the shortest path algorithm. The algorithm repeatedly executes a procedure which tries to maximize/minimize the return based on examining local conditions, with the hope that the outcome will lead to a desired outcome for the global problem. Typically, such algorithms employ simple strategies that are simple to implement and require minimal amount of resources and time, and this is attractive for the problem at hand. Dijkstra's establishes the shortest path (minimum of objective function) between a set of options (required number in each ground motion set) form the total population of choices (ground motion database). The followings constitute the steps for the optimization algorithm:

1. Create a set StdSet (shortest path set - ground motions set) that keeps track of selected ground motions, i.e. error calculated by equation 1 is calculated to be the minimum. Initially, this set is empty
2. Initialize an error value of very large value
3. While StdSet does not include the required number of ground motions in each set, the followings determine the ith component in StdSet
   - Pick a ground motion (j) from the database and which is not in StdSet, calculate the error term equation 1 and satisfy equation 3 with its penalty
   - If the error term calculated with the j^{th} component of database is the minimum so far, then include ground motion(j) to StdSet as i^{th} entry
   - Repeat through all ground motions in database

3 NUMERICAL EXAMPLE I: SELECTED SET OF GROUND MOTIONS

A design spectrum is used as the target spectrum, the full built database is used in the optimization algorithm. As each of the earthquake records are of two horizontal components, Square Root of Sum of Squares (SRSS) of the two spectrum components of every time record is used in the optimization. Most building codes state the need of seven ground motions to be used in the structural analysis, thus, the optimization problem is run to find the set of seven ground motions. Figure 1 shows the optimization results of the spectra matching the target spectrum using the average spectra, equation 1, without the extra condition on the values of the spectra being above the target spectrum (Case 1). Table 1 documents the identified ground motions for this case. Figure 2 shows the optimization results of the spectra matching the target spectrum

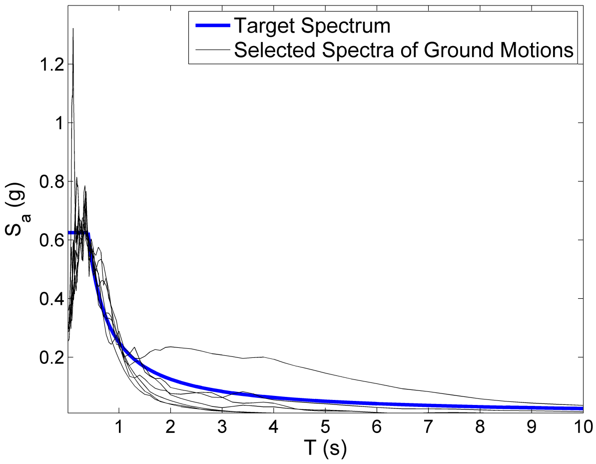

Figure 1: Selected and Scaled Spectra of Ground Motions for Case 1

No.	Year	Earthquake Name	Station	Scale Factor
1.	1999	Chi-Chi Taiwan	HWA032	1.6
2.	1971	San Fernando	Castaic	0.7
3.	1980	Livermore-02	San Ramon	1.0
4.	1994	Northridge-01	Manhattan Beach	1.2
5.	1987	Whittier Narrows-02	LA 116 St School	1.6
6.	1989	Loma Prieta	Fremont	1.3
7.	1999	Chi-Chi Taiwan	TCU075	0.6

Table 1: Selected Time Records for Case 1

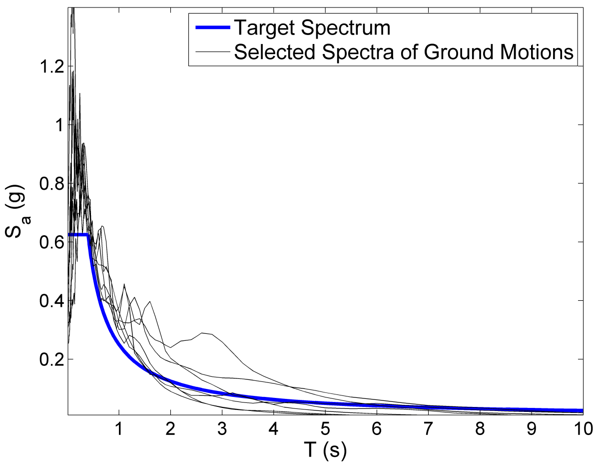

Figure 2: Selected and Scaled Spectra of Ground Motions for Case 2

No.	Year	Earthquake Name	Station	Scale Factor
1.	1979	Imperial Valley-06	EL Centro Array No.8	0.6
2.	1979	Imperial Valley-06	Aeropuerto Mexicali	0.8
3.	1980	Irpinia, Italy-01	Sturno	0.5
4.	1999	Chi-Chi, Taiwan	TCU129	0.4
5.	1979	Imperial Valley-06	Cerro Prieto	1.1
6.	1987	Baja California	Cerro Prieto	0.4
7.	1979	Coyote Lake	Gilroy Array No.6	0.6

Table 2: Selected Time Records for Case 2

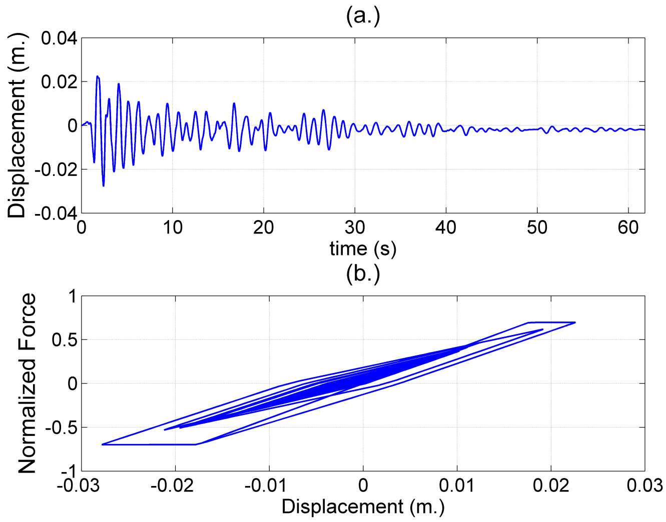

Figure 3: Nonlinear Analysis; a. displacement time history, b. force-deformation relation for the SDOF system

using the average spectra with the extra condition on the values of spectra being above the target spectrum; equations 1 & 3 (Case 2). Table 2 documents the identified ground motions for this case. It can be noticed that the optimized set of ground motions differed when using the condition on the values of the ground motions spectra, i.e. being above target spectrum. This highlights the importance of running an optimization problem to choose the ground motion records over the conventional way which is used extensively in the current engineering practice for seismic design and analysis.

4 NUMERICAL EXAMPLE II: NONLINEAR DYNAMIC ANALYSIS

A nonlinear analysis of SDOF system is performed to test the selected set of ground motions with their scaling factors. The nonlinearity of the system is modeled using an equivalent force-deformation relationship, the Takeda model is used to define the hysteresis model for the nonlinear dynamic problem. The definition of Takeda model needs various parameters to define the system at hand. The followings are the used parameters to define the Takeda model, it follows the equivalent force-deformation relationship for a moment resisting frame system; the unloading stiffness degradation parameter (α) is taken as 0.25, the reloading stiffness parameter (β) is taken as 0.0, post yield stiffness parameter (γ) is taken as 0.25, and elastic displacement limit is taken as 0.15m. The tested SDOF systems have 1 Hz as the natural frequency of vibration. A sample of the analysis results in terms of the displacement history and the system's hysteresis is presented in Figure 3. Furthermore, the maximum displacements and accelerations are illustrated in Table 4.

No.	Earthquake Name	Maximum Displacement (m.)	Maximum Acceleration (m/sec^2)
1.	Chi-Chi Taiwan	0.0298	2.3748
2.	San Fernando	0.0278	2.4799
3.	Livermore-02	0.0208	1.0824
4.	Northridge-01	0.0329	2.0273
5.	Whittier Narrows-02	0.0336	2.8466
6.	Loma Prieta	0.0346	2.6798
7.	Chi-Chi Taiwan	0.0344	1.5097

Table 3: Record of nonlinear analysis for selected ground motions for Case 1

No.	Earthquake Name	Maximum Displacement (m.)	Maximum Acceleration (m/sec^2)
1.	Imperial Valley-06	0.0479	3.4320
2.	Imperial Valley-06	0.0395	2.6328
3.	Irpinia, Italy-01	0.0399	1.6733
4.	Chi-Chi, Taiwan	0.0490	2.7881
5.	Imperial Valley-06	0.0358	2.1193
6.	Baja California	0.0621	3.6545
7.	Coyote Lake	0.0277	2.1094

Table 4: Record of nonlinear analysis for selected ground motions for Case 2

The design values are obtained by finding the average of the maximum responses of the seven records following most of the design codes. For Case 1:

- The average maximum displacements due to seven ground motions is (0.0308 m.) having a coefficient of variation of (0.168)
- The average maximum accelerations due to seven ground motions is (2.143 m/sec^2) having a coefficient of variation of (0.300)

For Case 2:

- The average maximum displacements due to seven ground motions is (0.0428 m.) having a coefficient of variation of (0.260)
- The average maximum accelerations due to seven ground motions is (2.629 m/sec^2) having a coefficient of variation of (0.276)

Two design values are used to compare the selection of ground motions following the case used in the optimization problem. The displacement indicates the damage level and the acceleration indicates the seismic forces. For the same optimization case, each design value has a different level of accuracy, this highlights the effect of target spectrum's type on the results. Acceleration spectrum is extensively used in seismic design and analysis, therefore, further research is needed to include displacement spectrum in the selection process. Furthermore, examining the accelerations' coefficient of variation in Case 1 and Case 2, it is noticed that the value drooped for Case 2. When adding the condition on the spectra values, the optimization problem yields, in general, different station records for the same earthquake that offers a good match to the target design spectrum, this may be the reason for the lower dispersion in Case 2, and showcases the power of the optimization problem formulated.

5 SUMMARY & CONCLUSION

The study offers an algorithm to create a set of ground motions using an optimization problem. The average of the selected ground motions over different periods is used in the optimization problem. Furthermore, a condition on the spectra values of selected ground motions is also included. It can be noticed that the set of ground motions differed when using the condition on the values of the ground motions spectra, i.e. being above target spectrum, which highlights the importance of running an optimization problem to choose the ground motion records over the conventional way which is used extensively in the current engineering practice for seismic design and analysis. Furthermore, for the same optimization case, each design value has a different level of accuracy, this highlights the effect of the target spectrum's type on the results. Therefore, further research is needed to include the displacement spectra in the selection and scaling process.

REFERENCES

[1] Browning J., Li R., Lynn A., Moehle J. P., *Performance Assessment for a Reinforced Concrete Building*, Earthquake Spectra 16(3), 2000 541–555

[2] Yakut A., Erduran E., *A Detailed Seismic Performance Assessment Procedure for RC Frame Building*, Advances in Earthquake Engineering for Urban Risk Reduction, Nato Science Series: IV: Earth and Environmental Sciences 66, 2006 135–150

[3] Kappos A. J., Panagopoulos G., *Performance Based Seismic Design of 3D R/C Buildings Using Inelastic Static and Dynamic Analysis Procedures*, ISET Journal of Earthquake Technology 41(1), 1411–148 2004

[4] Naeim F., Alimoradi A., Pezeshk S., *Selection and Scaling of Ground Motion Time Histories for Structural Design Using Genetic Algorithm*, Earthquake Spectra 20(2), 413–426 2004

[5] Jayarm N., Lin T., Baker J. W., *A Computationally Efficient Ground Motion Selection Algorithm for Matching a Target Response Spectrum Mean and Variance* Earthquake Spectra 27(3) 797–815 2011

[6] PEER. *Next Generation Attenuation Database* [Online] Available from http://peer.berkeley.edu/ngawest/ [Accessed: 10^{th} May 2015]